Prepared in cooperation with
DOUGLAS COUNTY UTILITY DIVISION

Maurer, D.K. and Peltz, L.A., 1994, Potential for, and possible effects of, artificial recharge in Carson Valley, Douglas County, Nevada

INTRODUCTION

Population growth in Carson Valley, west-central Nevada, is causing a change in land use from predominantly agricultural to urban and suburban. This change in land use is shifting water use from flood irrigation, supplied by runoff of the Carson River during the spring and early summer, to municipal use requiring a dependable year-round water source. Thus, the need to store water is increasing. Proposals for surface reservoirs have been discussed for decades; however, reservoirs are controversial and expensive. Another option is to increase the amount of water stored underground in Carson Valley by artificially recharging aquifers. Dillingham (1980, p. 31) estimates that more than 5 million acre-ft of water is stored in the upper 400 ft of aquifer material in Carson Valley. This natural subsurface reservoir could be used to store available surface water from the Carson River, and thereby conjunctively use both ground-water and surface-water supplies.

As a first step in determining potential areas for artificial recharge in Carson Valley, the U.S. Geological Survey (USGS), in cooperation with Douglas County Utility Division, studied related hydrologic factors during 1990-91. The results of this study can be used as a preliminary guide for site selection.

Purpose and Scope

This report discusses criteria for estimating the potential of an area for artificial recharge. These criteria were applied to available hydrogeologic data to delineate areas in Carson Valley within Douglas County that have high, moderate, low, or unknown potential for artificial recharge. An existing ground-water flow model was used to simulate the possible effects of artificial recharge. This study did not evaluate the effects of transporting water to sites; the cost of a recharge project relative to benefits; the legal and institutional constraints, such as obtaining title to land and water rights; or the effects of a project on interstate compacts, agreements among local agencies, or downstream water users.

Description of Study Area

Carson Valley lies mostly in Douglas County, Nev., and includes land that drains to the Carson River within the bounds of the study area (shown in figs. 1-9). Carson Valley covers an area of about 284,000 acres; about 46,000 acres are irrigated for agricultural use by water from the Carson River through a complex network of ditches and canals. Ground water is used for municipal supply and for irrigation in dry years when there is little surface water. As of 1981, ground-water withdrawals had not measurably changed ground-water storage (Maurer, 1986, p. 22). The East and West Forks of the Carson River originate in California in the Sierra Nevada and join to form the Carson River near Genoa. The river flows from south to north through Carson Valley, and continues about 90 mi to the east to discharge into the Carson Sink–an ephemeral lake northeast of Fallon, Nev. (fig. 1). The Carson Range bounds the valley on the west (fig. 2), reaching an altitude of about 10,000 ft above sea level, and receives up to 45 in. of precipitation annually. The Pine Nut Mountains bound the valley on the east, reaching an altitude of up to 9,000 ft, and receive up to 25 in. of precipitation annually. The valley floor lies in the rain shadow of the Sierra Nevada, at an altitude of about 4,800 ft, and receives less than 10 in. of precipitation annually.

About 17 million years ago, movement began along several faults, uplifting the granitic and metamorphic rocks that make up the mountain blocks and downdropping the valley floor (Stewart, 1980, p. 110). This movement created a basin that today is filled with semiconsolidated and unconsolidated sediments more than 5,000 ft thick (Maurer, 1986, pl. 2). From about 15 to 5 million years ago, mostly fine-grained sediments were deposited that have since become semi-consolidated. Continued faulting tilted these sediments to the west and exposed them mainly on the eastern side of the basin (fig. 2). From about 2 million years ago to the present, the basin has filled with unconsolidated sediments, consisting of silt, sand, and gravel deposited by the Carson River in the center of the basin, and with alluvial-fan deposits from numerous streams along the base of the mountain blocks.

Unconsolidated sediments in the valley form the major ground-water reservoir in Carson Valley. In the mountain blocks, ground water is found mainly in fractured and weathered zones in the bedrock, and storage capacity is minimal. In the semiconsolidated sediments, storage capacity may be considerable; however, ground water moves mainly through thin, discontinuous coarse-grained layers, and thus, moves slowly through the unit as a whole.

The unconsolidated sediments are recharged by (1) infiltration of streamflow of the Carson River, (2) infiltration of streamflow on alluvial fans surrounding the valley floor, (3) subsurface ground-water flow from the mountain blocks and semiconsolidated sediments, and (4) infiltration of precipitation during winter months (Maurer, 1986, p. 102).

Ground water flows from the west and east toward the Carson River and then follows the course of the river down the slope of the valley floor from south to north. The Carson River supplies water for flood irrigation on the valley floor through an extensive system of unlined ditches and canals. Leakage from this system and from flood irrigation maintains a shallow water table, typically within a few feet of land surface, over much of the valley floor. Depth to saturated sediments is more than 200 ft beneath the alluvial fans near the perimeter of the valley. Where the water table is below the stream and ditch bottoms—generally beneath the alluvial fans and near the southern end of the valley, surface water recharges the ground-water reservoir. Where the water table is above the stream and ditch bottoms, generally near the western and northern sides of the valley floor, the surface-water system drains the ground-water reservoir.

Along the base of alluvial fans on the western side of the valley floor, recharge from the mountain blocks, combined with the steep slopes of the alluvial fans, creates artesian pressures that cause wells deeper than about 50 ft to flow. Elsewhere beneath large parts of the valley floor, discontinuous clay beds combined with the south-to-north slope of the floor create a semiconfined aquifer about 200 ft below land surface. Flowing wells deeper than about 200 ft have pressure heads of 5 to 20 ft above land surface, and a large component of ground-water flow is upward over much of the western and northern sides of the valley floor (Maurer, 1986, p. 46).

Definition of Hydrogeologic Terms

In an unconfined aquifer, the relation between ground-water storage and head, called *specific yield*, is defined as the change in storage per unit area of aquifer as a result of a unit change in head, and is usually expressed as a percentage. The water is derived from dewatering pore spaces between sediment grains in the aquifer material. Specific yield is proportional to the grain size of the aquifer material and is greater in well-sorted than in poorly sorted sediments. Specific yield is less where aquifer sediments are consolidated or cemented. In Carson Valley, specific yield ranges from less than 5 percent to more than 25 percent.

CONVERSION FACTORS, WATER-QUALITY UNIT, AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
inch (in)	2.540	centimeter
inch per hour (in/h)	2.540	centimeter per hour
square mile (mi^2)	2.590	square kilometer

Abbreviated Water-Quality Unit Used In This Report
mg/L (milligram per liter)

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called "Sea-Level Datum of 1929"), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

In both confined and semiconfined aquifers, the aquifer material is not actually drained when the head declines; the water in the aquifer expands and the aquifer material compresses to release water. The volume of water released from or taken into storage per unit volume of the confined aquifer, per unit change in head, is called *specific storage*. This amount is small, usually less than 1 percent, compared with the volume of water derived from a unit decline in an unconfined aquifer. In semiconfined aquifers, the confining bed is thin or discontinuous, allowing upward flow, or leakage.

Hydraulic conductivity is a measure of how easily water moves through an aquifer; it is defined as the volume of water moving through a unit area of aquifer under a unit hydraulic gradient per unit time at prevailing kinematic viscosity. Hydraulic conductivity is proportional to the grain size of the aquifer material; it is greater in well-sorted than in poorly sorted sediments, and it is smaller where sediments are consolidated or cemented. The average hydraulic conductivity of an entire aquifer also depends on the vertical distribution of coarse- and fine-grained layers in the aquifer and is commonly greater in the horizontal direction than in the vertical direction (Freeze and Cherry, 1979, p. 34). In Carson Valley, horizontal hydraulic conductivity ranges from about 0.9 to 90 ft/d (Maurer, 1986, p. 30).

Infiltration rate indicates how rapidly water enters the subsurface; it is expressed in units of distance per unit time. Infiltration rate is a function of the grain size, sorting, consolidation, and cementation of the sediments and the depth of ponding. *Percolation rate* indicates how rapidly water moves from the surface to the water table; it also is expressed in units of distance per unit time. Percolation rate is highly dependent on the vertical unsaturated hydraulic conductivity, which is a function of the moisture content of the sediments. Both infiltration and percolation rates can be greatly affected by conditions near land surface, such as soil cracks or rodent burrows.

OVERVIEW OF ARTIFICIAL RECHARGE

Artificial recharge is a process whereby water is added to an aquifer to supplement the normal recharge. This additional recharge can be supplied by flooding prepared infiltration beds, ditches, or pits with available surface water, which percolates down to the water table. Recharge water can also be injected through wells where urban development limits the area available for infiltration beds, where recharge must reach a deep water table, or where recharge must penetrate confining beds to reach a confined aquifer (Huisman and Olsthoorn, 1983, p. 16). Adding water to an unconfined aquifer creates a mound in the water table at the point of recharge; adding water to a confined aquifer increases pressure head near the area where water is injected.

Underground storage of water by means of artificial recharge has advantages in comparison with surface-water storage in reservoirs. Advantages include lower construction costs, decreases in water lost to evaporation, and a more dependable, year-round supply (Espina, 1980, p. 7). Also, with careful design, artificial recharge using storm runoff from urban areas or reclaimed wastewater is a feasible and economic means of conserving resources (Todd, 1980, p. 475, and O'Hare, 1985, p. 254). Asano (1985, p. 10) and O'Hare (1985, p. 254) note that water quality from these sources generally improves through recharge, because some contaminants are filtered and adsorbed as the water percolates through soil in infiltration beds.

Conversely, underground storage of water has disadvantages compared with storage in surface reservoirs. These include cost and complexity of site selection, operational problems, potential effects on ground-water quality, and water loss by uncontrolled ground-water discharge (O'Hare, 1985, p. 254 and 262; Bouwer, 1988, p. 111). Some disadvantages can be minimized by careful engineering, design, and management of the artificial recharge project.

Bianchi and others (1978, p. 178 and 180) caution that the capacity for recharge in an area is difficult to predict even using site-specific data collected during pilot studies; they also note that the efficiency of a recharge project may be controlled more by management of the project than by hydrogeologic conditions. Consequently, they suggest that the preliminary facility design should be conservative, yet flexible, to allow expansion if justified by project performance. Thus, considerable site-specific investigation would be needed for final site selection, followed by a period of monitoring and evaluation to determine the actual effectiveness and recharge capacity of the site.

Because ground water cannot be withdrawn from storage in large volumes at any one place, as it can from surface reservoirs, many wells may be needed to pump water out of storage. Other operational problems center on clogging of infiltration surfaces or aquifer pore space by (1) sediments suspended in the recharge water, (2) mineral precipitation from chemical reactions between recharge water and native ground water or aquifer sediments, (3) algal or microbial growth, or (4) air (Todd, 1980, p. 473; O'Hare, 1985, p. 254). A settling basin or a coagulation-flocculation system can usually minimize clogging by suspended sediments. Infiltration systems can be managed by alternating wet and dry periods; the dry periods kill algal or microbial growths and allow for reworking of bed materials (Todd, 1980, p. 473). If mineral precipitation is anticipated, further pretreatment of recharge water could be needed. Clogging by air entrainment can be minimized by designs that reduce the exposure of recharge water to the atmosphere (O'Hare, 1985, p. 258).

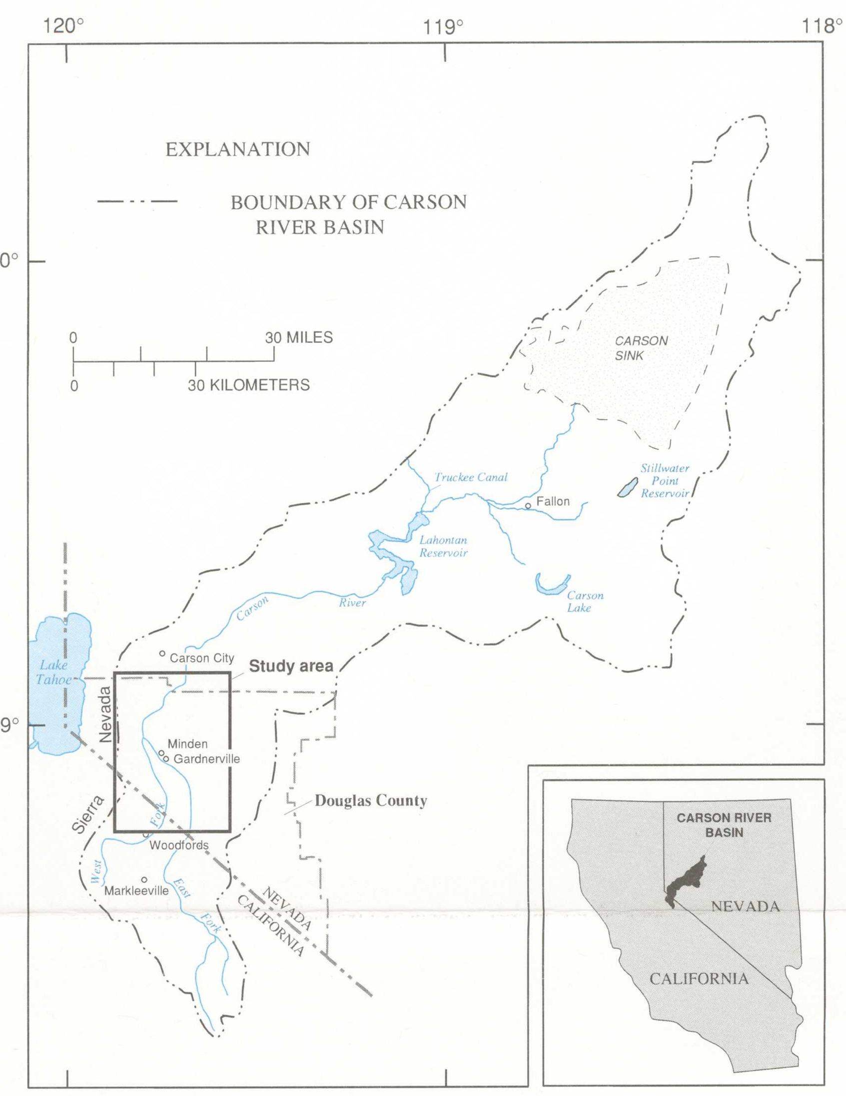


Figure 1. Location of Carson River Basin, Douglas County, and study area.

Ground-water quality near the recharge site may deteriorate if the recharge water saturates previously unsaturated sediments and dissolves soluble minerals in the sediments. Also, if storm runoff or wastewater is used for recharge, further pretreatment could be needed–such as activated charcoal filtration, chlorination, air stripping of organic compounds, or reverse osmosis (Asano, 1985, p. 209). The amount of pretreatment needed is greater for injection systems that add water directly to the aquifer than for infiltration systems.

Because aquifers are not closed systems, water stored underground can be lost as it flows from recharge areas to discharge areas. Careful site selection, design, and management of recharge facilities can minimize this loss.

Finally, O'Hare (1985, p. 258) points out certain factors are often neglected in feasability studies for recharge projects. Some of these factors are transportation of water to sites; cost of a recharge project relative to benefits; legal and institutional constraints (e.g., obtaining title to land and water rights); or effects of a project on interstate compacts, agreements among local agencies, or downstream water users. Espina (1980, p. 10) notes that the sociological and economic aspects of increasing ground-water supplies are other considerations for land-use planners and water managers.

CRITERIA USED TO ESTIMATE RECHARGE POTENTIAL

Criteria used to estimate potential for recharge in Carson Valley are based on (1) hydrogeologic factors that reportedly control recharge efficiency, and (2) the types of data available for large parts of Carson Valley that can be used to estimate or define the hydrogeologic factors.

Hydrogeologic factors that control the efficiency of artificial recharge include (1) rate of infiltration through surface materials, (2) rate of percolation to the water table, (3) thickness of and depth to water-bearing units, (4) existence of fine-grained layers that can impede recharge, (5) capacity for storage (specific yield or specific storage) in the aquifer, (6) rate of horizontal movement of water (hydraulic conductivity) in the aquifer, (7) type of aquifer to be recharged (confined or unconfined), and (8) location of natural recharge and discharge in the hydrologic system (Asano, 1985, p. 95; Hamlin, 1987, p. 8; O'Hare, 1985, p. 253). Optimum values for the hydrogeologic factors that can be quantified have not been developed, because they also depend on the volume of water available for recharge, the desired rate and schedule for ground-water withdrawal, and the management scheme at a given site (Bianchi and others, 1978, p. 176). Lichtler and others (1980, p. 102) used an infiltration rate of 0.25 in/h as the minimum acceptable value for recharge operations. Todd (1980, p. 474) indicates 10 to 20 ft as a minimum depth to water that would allow additional ground-water storage above the water table. Mitten (1982, p. 10) arbitrarily selected specific yield equal to or greater than 10 percent as a criterion to delineate areas with high potential for artificial recharge. O'Hare (1985, p. 253) states qualitatively that aquifers having high specific storage or specific yield and high hydraulic conductivity, mineral compositions that do not cause clogging of aquifer pore space, and natural recharge sites have a high potential for artificial recharge.

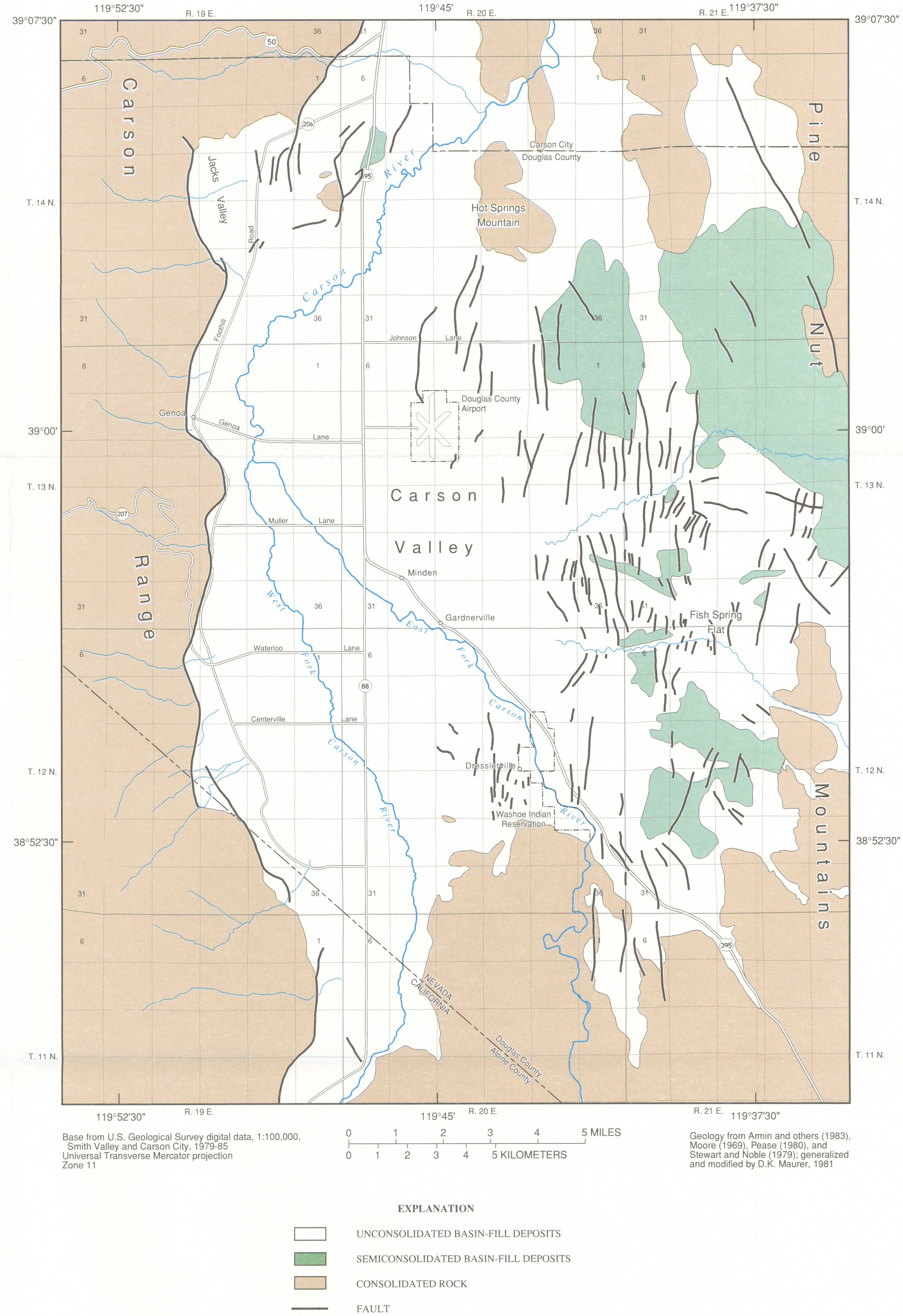
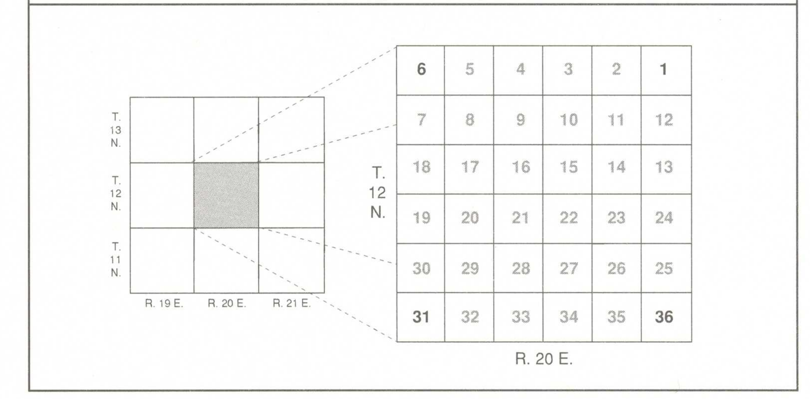


Figure 2. Distribution of consolidated rock, semiconsolidated and unconsolidated basin-fill deposits, and faults.

NUMBERING CONVENTION FOR SECTIONS IN TOWNSHIP AND RANGE GRID, MOUNT DIABLO BASELINE AND MERIDIAN



Criteria used in this report for delineating the potential of an area for artificial recharge are based on the following general guidelines and assumptions: For infiltration systems, infiltration rate and percolation rate should be as fast as possible. Because percolation rate is highly dependent on subsurface moisture content and vertical unsaturated hydraulic conductivity, which have not been measured in Carson Valley, areas with fast infiltration rates are assumed to also have fast percolation rates. The depth to water should be sufficient to accommodate the rise in water levels with recharge, yet not so deep that recharging water will take too long to percolate to the water table or be lost to perched or partly saturated zones above the water table. Because detailed lithologic data are lacking for many areas of Carson Valley, areas with high specific yield are assumed less likely to have fine-grained layers that could impede recharge from infiltration. For both infiltration and injection systems, hydraulic conductivity and specific yield or specific storage of the aquifer should be maximum values. For infiltration and injection systems, areas of natural recharge are preferable to areas of natural discharge to minimize the loss of recharged water to evapotranspiration or discharge to streams (O'Hare, 1985, p. 253; Todd, 1980, p. 481).

Data that are readily available for large areas of Carson Valley and applicable in defining the hydrogeologic factors discussed above are limited to (1) mapped geology, (2) depth to water, (3) hydraulic conductivity, (4) specific yield, and (5) infiltration rates. The geology in Carson Valley was generalized by Maurer (1986). The depth to water beneath large parts of Carson Valley has been measured by the U.S. Geological Survey from about 1981 to 1991 and is reported by drillers when wells are drilled. The hydraulic conductivity of aquifer materials beneath Carson Valley was estimated for areas covering 1 mi^2 by Maurer (1986, p. 57). These average values were not considered appropriate for defining the recharge potential for specific areas of Carson Valley. The specific yield of aquifer materials beneath Carson Valley was estimated by Dillingham (1980) and infiltration rates of soils mapped in Carson Valley were estimated by the U.S. Soil Conservation Service.

As discussed in the following sections, the geology mapped within the basin was used to delineate areas where artificial recharge is feasible. The depth to water was used to delineate aquifer type, areas of natural recharge and discharge, and areas where aquifers could be recharged by either infiltration or injection. Infiltration rate was used to delineate areas with high, moderate, and low potential for recharge by infiltration; specific yield was used to delineate areas with high and moderate potential for recharge by injection.

In this study, the chemical and physical quality of recharge and ground water and the mineral composition of aquifer materials were not considered as factors for evaluating potential for artificial recharge. In the study area, both surface water of the Carson River and ground water in Carson Valley are calcium and sodium bicarbonate waters (Welch, in press). The surface water is more dilute than the ground water: dissolved-solids concentrations range from 30 to 400 mg/L in surface water, compared with as much as 1,000 mg/L in ground water. Welch (in press) suggests that the major dissolved constituents in the ground water are derived from dissolution of minerals in the aquifer, and this process produces clay minerals. The clay minerals coat grains in the aquifer but probably do not decrease available storage (Alan H. Welch, U.S. Geological Survey, oral commun., 1991). Thus, the potential for clogging of aquifer pore space as a result of reaction between recharge water from the Carson River and ground water or aquifer minerals is probably minimal. If storm runoff or wastewater are to be used for recharging, the potential for chemical reactions will be an important part of the site-specific system design.

Saturation of previously unsaturated aquifer material could cause dissolution of iron and magnesium oxide coatings on sediments and increase concentrations of dissolved iron and manganese. Welch (in press) suggests that this process might be occurring on the northern and eastern sides of the valley, where concentrations of iron and manganese in ground water exceed Nevada drinking-water standards (Welch and others, 1989, p. 42). Detailed analyses of ground water and aquifer mineralogy would allow evaluation of the potential for similar dissolution near artificial recharge sites.

Mapped Geology

Because of the low permeability of consolidated bedrock and semi-consolidated sediments, areas where these are exposed (fig. 2) probably have little or no potential for artificial recharge. Areas near these exposures could have low potential for recharge, because the less permeable rocks are probably near the surface and aquifer thickness is small. Detailed investigations of sites near exposures of consolidated rock and semiconsolidated sediments would determine the available aquifer thickness. Areas underlain by unconsolidated sediments east of exposed bedrock on the eastern side of Fish Spring Flat (fig. 2) likely have consolidated or semiconsolidated sediments at shallow depths and thus have little or no potential for artificial recharge.

Faults can restrict ground-water flow from a recharge site to the point of ground-water withdrawal by offsetting or damming water-bearing units. Conversely, faults can aid recharge by holding flow within the area of the site and the withdrawal well. Mapped faults are shown in figure 2. Detailed investigations of sites near faults could determine the effect of the faults on local ground-water flow.

POTENTIAL FOR, AND POSSIBLE EFFECTS OF, ARTIFICIAL RECHARGE IN CARSON VALLEY, DOUGLAS COUNTY, NEVADA

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